Int J Adv Manuf Technol (2012) 60:939–950
DOI 10.1007/s00170-011-3657-z

ORIGINAL ARTICLE

Enhancement and verification of a machined surface quality for glass milling operation using CBN grinding tool—Taguchi approach

M. Sayuti · Ahmed A. D. Sarhan · M. Fadzil · M. Hamdi

Received: 11 January 2011 / Accepted: 19 September 2011 / Published online: 2 October 2011

Abstract Nowadays, the demand for high product quality focuses extensive attention to the quality of machined surface. The (CNC) milling machine facilities provides a wide variety of parameters set-up, making the machining process on the glass excellent in manufacturing complicated special products compared with other machining processes. However, the application of grinding process on the CNC milling machine could be an ideal solution to improve the product quality, but adopting the right machining parameters is required. Taguchi optimization method was used to estimate optimum machining parameters with standard orthogonal array L_{16} (4^4) to replace the conventional trial and error method as it is time-consuming. Moreover, analyses on surface roughness and cutting force are applied which are partial determinant of the quality of surface and cutting process. These analyses are conducted using signal to noise (S/N) response analysis and the analysis of variance (Pareto ANOVA) to determine which process parameters are statistically significant. In glass milling operation, several machining parameters are considered to be significant in affecting surface roughness and cutting forces. These parameters include the lubrication pressure, spindle speed, feed rate, and depth of cut as control factors. While, the lubrication direction is considered as a noise factor in the experiments. Finally, verification tests are carried out to investigate the improvement of the optimization. The results showed an improvement of 49.02% and 26.28% in the surface roughness and cutting force performance, respectively.

Keywords CNC machine · Glass milling · Grinding · Taguchi · Optimization · Surface roughness · Cutting force

1 Introduction

Glass is generally known as a hard, brittle, solid, and transparent material. The optical and physical properties of glass play an essential role for many different industrial applications. Soda-lime glass is one of the most prevalent types of glass, which is widely used and can easily be found on the market. In industry, this type of glass is the most commonly produced since it is easy to make with better cost-effectiveness compared with other types of glass [1]. In addition, it also has good mechanical properties in terms of hardness, refractive index, and melting temperature [2]. In silicone industry as an example, soda-lime glass has been used as a mold with a very good precision in terms of dimensional accuracy even at elevated temperatures. While using a very high precision glass mold, the shape varieties of the silicone product lead to many different complicated shapes of glass molds to be developed [1]. However, unique properties of soda-lime glass, such as compressive hardness and brittleness, make any machining of glass a very challenging process [3–8]. Glass milling would be a good process required especially in producing varieties shape of slot on glass surface. The capability of the CNC milling machine to make batch production would be a noteworthy advantage for glass machining. However, the demand for high quality focuses

M. Sayuti (✉) · A. A. D. Sarhan · M. Fadzil · M. Hamdi
Centre of Advanced Manufacturing and Material Processing,
Department of Engineering Design and Manufacture,
University of Malaya,
Lembah Pantai Kuala Lumpur 50603, Malaysia
e-mail: mdsayuti@siswa.um.edu.my

A. A. D. Sarhan
Department of Mechanical Engineering, Faculty of Engineering,
Assiut University,
Assiut 71516, Egypt

Table 1 The control factors and experimental condition levels

Control factors		Control factor levels (i)			
		i=1	i=2	i=3	i=4
A	Lubrication pressure (MPa)	0.4	0.6	0.8	1.0
B	Spindle speed (min^{-1})	5,000	10,000	15,000	20,000
C	Feed rate (mm/min)	0.5	1	1.5	2
D	Axial depth of cut (mm)	0.25	0.5	0.75	1

attention on the surface condition and the quality of the product, especially the roughness of the machined surface, because of its effect on product appearance, function, and reliability [9, 10]. Hence, the application of grinding process on the CNC milling machine is found to be an ideal solution in manufacturing complicated special products, making the machined surface quality on the glass mold superlative compared with other machining.

Surface roughness is defined as a group of irregular waves in the surface, measured in micrometers (μm). The roughness data obtained by measurement can be manipulated to determine the roughness parameter. There are many different roughness parameters in use, but R_a is the most common. Other common parameters include R_z, R_q, and R_{sk}. Surface roughness is mainly affected by different controlled machining parameters that can be set up in advance, such as spindle speed, feed rate, depth of cut, and lubrication pressure. However, it is also affected by other uncontrolled variables such as the mechanical properties of the workpiece material, the type of the cutter, and the vibration produced during the process [11]. In metal machining, the use of higher cutting speed and lower feed rate and depth of cut produced a better surface finish and this is mainly attributed to the high temperature generated in the interface [9, 12]. However, in glass machining, the effect of these parameters needs to be investigated, but in general, with higher cutting speed and higher temperature, special rapid tooling is needed to increase abrasion resistance and hence produce good surface roughness. Cubic boron nitride (CBN) grinding tools are traditionally expected to play multiple roles, such as reducing cutting temperatures and cutting forces and increasing abrasion resistance. The cutting temperature is a key factor, which directly affects tool quality, workpiece surface integrity, and machining precision according to the relative motion between the tool and workpiece. The amount of heat generated varies with the type of workpiece material being machined and machining parameters used especially cutting speed, which had the most influence on the temperature [13]. Therefore, the implementations of cutting fluid, which not only act as a lubricant, but also work as a coolant, are very crucial to control the temperature for better surface finish.

Following the literature above, for optimization of glass milling process in minimizing the surface roughness and cutting force, this study has been conducted by anticipating lubrication pressure, spindle speed, feed rate, and depth of cut as control variables. In addition, the lubrication direction is another important factor impacting the surface quality. It is considered as a noise factor as it is hard to categorize its degree of performance to control the cutting temperature. The main objective of this research work is to find the best combination of these parameters in glass milling operation using CBN grinding tool to get lower cutting force and best surface roughness. The conventional method to achieve that is to use the "trial and error" approach. However, "trial and error" approach is very time-consuming due to the requirement of a large number of experiments. Hence, a reliable systematic approach for optimizing the machining parameters is thus required. Taguchi optimization method is an efficient, effective, reliable, and simpler approach, in which the response

Table 2 Standard $L_{16}(4)^4$ orthogonal array

Exp. no.	Control factors and levels (i)			
	A	B	C	D
1	i=1	1	1	1
2	i=1	2	2	2
3	i=1	3	3	3
4	i=1	4	4	4
5	i=2	1	2	3
6	i=2	2	1	4
7	i=2	3	4	1
8	i=2	4	3	2
9	i=3	1	3	4
10	i=3	2	4	3
11	i=3	3	1	2
12	i=3	4	2	1
13	i=4	1	4	2
14	i=4	2	3	1
15	i=4	3	2	4
16	i=4	4	1	3

The 16 experiments with the details of the combination levels